

Nov 18th, 12:00 AM

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Baker, James L.; Ressler, Daniel E.; Horton, Robert; and Kaspar, Thomas C., "New Nitrogen Application/Placement Techniques to Increase Use-Efficiency and Reduce Nitrate Leaching" (1998). *Proceedings of the Integrated Crop Management Conference*. 25.
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NEW NITROGEN APPLICATION/PLACEMENT TECHNIQUES TO INCREASE USE-EFFICIENCY AND REDUCE NITRATE LEACHING

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Introduction

Nitrogen (N) fertilizer is used extensively in corn production in Iowa and the north-central region. In 1997, the 12.2 million acres of corn grown in Iowa received an average of 121 lb/acre of N fertilizer; corresponding values for the region were 62.2 million acres and 130 lb/acre (USDA-NASS, 1998). Excess water leaving the root zone from this cropland is needed to replenish surface and groundwater supplies; however, the nitrate-nitrogen ($\text{NO}_3\text{-N}$) this water carries can contaminate both of these resources. Baker et al. (1975), Baker and Johnson (1981), and others in the region (e.g., Gast et al., 1978; Kladvik et al., 1991) have shown that $\text{NO}_3\text{-N}$ in subsurface drainage water from row-crop land usually exceeds 10 mg/L, the drinking water standard, with annual leaching losses averaging over 15 lb/acre. This water, if not intercepted by tile drains, can percolate to groundwater and cause contamination there. Drainage water intercepted by tile drains and short-circuited back to surface waters can cause contamination there. Studies (e.g., Johnson and Baker, 1982 and 1984; Hatfield et al., 1995) have shown that streams and rivers in Iowa, whose flow is often dominated by shallow subsurface drainage, can have sustained high levels of $\text{NO}_3\text{-N}$ in the range of 10 mg/L. In addition to concerns for drinking water quality, $\text{NO}_3\text{-N}$ contamination of water in drainage to the Mississippi River from Iowa and the north-central region has been implicated as a possible cause of a hypoxic or "dead zone" in the Gulf of Mexico (Rabalais et al., 1996). Therefore, improved management of N fertilizer is needed to decrease contamination from this source.

Nitrate, because it is soluble and not adsorbed, will readily move with water through the soil profile. Leaching loss is a product of $\text{NO}_3\text{-N}$ concentration and volume of leaching water. One

approach to reduce leaching is to improve N management by decreasing the amount available to be leached, thus reducing concentrations in leaching water. For example, Kanwar et al. (1988) have shown that split, low rate applications of N rather than higher single applications can reduce $\text{NO}_3\text{-N}$ concentrations in tile drainage water and maintain corn yields.

Another approach to reducing $\text{NO}_3\text{-N}$ concentrations would be to place N away from the flow path of leaching water. Kanwar et al. (1985) and Juo and Lal (1979) found decreased $\text{NO}_3\text{-N}$ leaching with no-till, whereas others (Tyler and Thomas, 1977) found increased leaching. One explanation for the difference is that, in the first instance, the $\text{NO}_3\text{-N}$ was "unavailable" within soil aggregates and was bypassed by water flowing in larger pores, sometimes termed macropores, whereas in the second case, the $\text{NO}_3\text{-N}$ was available to water flowing in the macropores. The measured effects of tillage systems, macropores, and compaction on water flow and $\text{NO}_3\text{-N}$ leaching indicate that management of these effects with respect to placement of N fertilizer offers the potential to manage soil around the fertilizer band to reduce $\text{NO}_3\text{-N}$ leaching. Kiuchi et al. (1994) measured the effects of different subsurface barriers on delaying and reducing anion leaching. Compacted soil was one of the barriers studied and all barriers delayed the first detection and reduced peak concentrations of chloride, with the barrier cross-sectional areas being $\leq 8\%$ of the column cross-section.

In a practical sense, it was felt that N applicators could be modified to divert the route of water movement away from the location of a mobile anion like $\text{NO}_3\text{-N}$. This could be done by utilizing the point-injector fertilizer applicator (Baker et al., 1989) with ridge-tillage or by modifying a conventional knife applicator (Ressler et al., 1997); see Figures 1 and 2, respectively, for schematic diagrams of these applicators in use. The purpose of this paper is to review recent and on-going work relative to this concept.

Rainfall Simulation/Column Leaching Study

The objective of this study (Baker et al., 1997) was to determine the effect of selective soil compaction to reduce anion leaching by altering water movement in the zone of anion application. The anion used was bromide (Br) applied as a potassium bromide (KBr) salt solution. A secondary objective was to increase the understanding of water and anion movement through soil with measurements not only of the applied Br, but also of the $\text{NO}_3\text{-N}$ present in the soil at the time of simulation. Soil columns (30 x 30 x 12" deep) were removed intact from two different tillage plots (no-till and chisel plow), transported to the laboratory, treated with KBr three different ways, and rained on. Water draining from the columns was weighed and analyzed for the Br, and $\text{NO}_3\text{-N}$. The soil was a Treaty silt loam with an organic carbon content of about 2.7%; soil pH of 6.4; and 21, 50, and 29% sand, silt, and clay, respectively.

For columns that received a point injection either with compaction (CPI) or without (PI), KBr was applied at 133 lb/acre by injecting solution about 3" deep in each of four holes. The holes were in a line parallel to and about 8" from a previous soybean row and were about 8" apart. For the CPI treatment, the soil in a 4" diameter area around the holes was compacted by repeatedly dropping a metal rod from a height of 4". The resultant depressions (about 1½" deep for no till and slightly deeper for chisel plow) were refilled with topsoil. The third treatment was broadcast spraying (B), of Br solution on the total column surface by using a flat-fan nozzle.

Two rainfalls of 2 h each, separated by 1 h, were simulated. The average time between the beginning of rainfall and drainage from the bottom of the columns was 25 min, which meant at 1.5"/h, 0.6" of water was applied before drainage began. The average amount of water retained by the columns (total rainfall minus total drainage) was 1.1". If the columns could be considered to be at field capacity when drainage stopped, based on the difference of 0.5" between the water stored at the end of the run and the amount of water it took to cause drainage, drainage began well before the columns reached a moisture content that would be termed field capacity.

Average drainage volumes and flow-weighted anion concentrations and leaching losses are given in Table 1. Drainage volumes would not be expected to be affected by placement treatments, and they were not. For both no-till and chisel plow, Br concentrations and losses for the CPI treatment were significantly lower than the other placement treatments. The difference in losses between the B and the CPI treatments (a factor of ten for NT and seven for CP) illustrates the large potential of localized compaction to reduce anion leaching. That the difference between the PI and the CPI treatments is similar to that between B and CPI verifies that the effect was due to compaction and not to point injection.

From soil sampling it was determined that the concentration of $\text{NO}_3\text{-N}$ in the soil water remaining in the bottom layer of the column was about 2.5 times that in the last drainage sample taken. Hence, the $\text{NO}_3\text{-N}$ present at the time of simulation was not as positionally available to leaching water as the surface applied Br for which the ratios of concentrations in soil water to drainage were from 1.0 to 1.3. This is further illustrated in Table 1 where the percentages of $\text{NO}_3\text{-N}$ losses (based on that present in the columns at the beginning of rainfall) for both the B and PI treatments were about half those for the percentages of Br losses (based on that applied). The potential of the CPI treatment to reduce leaching of applied anions is also further illustrated by the five- to seven-fold reduction of Br losses relative to $\text{NO}_3\text{-N}$ losses.

Lysimeter Leaching Study

The applicator shown in Figure 2 was the subject of a leaching study (Ressler, et al., 1998a) conducted in tanks of soil, or lysimeters, at the research center west of Ames, IA. This applicator, termed the localized compaction and doming (LCD) applicator, places liquid N fertilizer in a line source or band similar to conventional knife applicators, except that it has a horizontal blade at the bottom of the knife (almost like a section from a sickle mower) that can cut and smear any macropores in the vicinity of the applied N. In addition, a trailing cone wheel locally compacts the soil over the band and a further trailing disk slightly domes the soil over the compacted area. Thus, the localized smearing, compaction, and doming should divert some rain water away from the band of N and reduce $\text{NO}_3\text{-N}$ leaching.

The primary objective of this study was to determine the effect of the LCD applicator on solute movement by determining the mass of injected or surface-applied fluorobenzoic acid tracers (which are used as surrogates for $\text{NO}_3\text{-N}$) in subsurface drain tube water 4' below the soil surface. Three application treatments were used: (i) injection by a conventional knife injector; (ii) broadcast application on the soil surface; and (iii) injection by a LCD applicator. Drainage water was monitored to determine the volume of drainage and mass of each anion that leached.

A second objective was to evaluate the interaction of two rainfall intensities on solute movement. A high-intensity rainfall treatment, including infrequent storms, some of which had rainfall intensities > 1 "/h, was compared with a low-intensity rainfall treatment, which included more frequent rains of smaller volumes and intensities.

The soil in the lysimeters (38 x 90 x 54" deep) was a Nicollet silt loam; a 4" perforated tube at the bottom of each plastic (Hypolon) lined lysimeter was used to collect water for quantity and quality measurements. The soil surface in all the lysimeters was tilled before chemical application. The three application treatments were applied to each lysimeter, each with a different anion tracer; the broadcast application was made with a flat-fan nozzle.

Three days after chemical application, all lysimeters received the first simulated rainfall of 2" at 2"/h. Over the next 120 d, the low intensity rainfall treatment received a second simulated rain of 0.7" and a total of 9.5" of natural rainfall, all at less than 0.8"/h. Over the same period, the high intensity rainfall treatment received three more simulated rains at 1 to 1.5"/h totaling 5.0". Tarps were used to exclude enough (about 4.3") natural rainfall in order that the total rainfall amounts for the two treatments were approximately equal. Drainage began with the first simulated rain and totaled about 4" in the first four-month period (July-Nov.) and about 4" in the next twelve-month period (Nov.-Nov.).

Detectable levels of chemicals from all three application treatments were found in drainage from the first 2" simulated rainfall, indicating "by-pass" or macropore flow. Data in Table 2 show the percentages of the 56 lb/acre of each tracer applied by the three different methods that was lost for the two rainfall intensities and two periods of measurement. In all cases, smaller percentages of the anions were lost with the drainage water when the anions were applied with the LCD applicator.

Soil Sampling/Yield Field Study

The objectives of this two-phased study (Ressler et al., 1998b) comparing the LCD and knife applicators under natural rainfall/field conditions were to 1) measure the relative effect of the LCD applicator on anion leaching and 2) evaluate the corn yield response to N applied with the two applicators. Intensive soil sampling over a two-year period (1993-94) was used to determine the distribution of applied $\text{NO}_3\text{-N}$ and Br (115 and 126 lb/acre, respectively) to a depth of 32" below the soil surface. Soil samples were collected from a vertical pit wall spanning three corn rows and two interrows (60" total) at selected times after application. Four sets of soil blocks 15" wide (two centered on the interrow injection lines; the other two in effect centered on the corn rows) were taken 4" into the pit face in four 8" long depth increments to the 32" depth and extracted and analyzed for the applied anions.

Corn yield response to 0, 60, 100, 140, and 180 lb N/acre applied with the two applicators were determined on continuous corn plots that were 12.5 x 60' long for each of the two years (1995-96). The N source was a 28% UAN solution and the soil in the plot areas for both the leaching and yield studies was Nicollet silt loam. Corn yield data (bu/acre) were collected and fitted using a quadratic-plateau model. The end-of-season corn stalk nitrate test was also run.

The first year of the leaching study (1993) was wetter than average with 17" of rain during the first 38 d after fertilizer injection in the spring, followed by 12" during the next 45 d, with the total of 29" about 20" above average. Soil sampling for those two times (38 and 83 d after application) in 1993 showed that the LCD applicator retained more $\text{NO}_3\text{-N}$ and Br in the top 32" of soil than for the knife applicator with the additional amounts retained being 23 and 22 lb/acre, respectively, 83 d after application. Rainfall during the second year of the leaching study, rainfall was about 10% below average for each of the three sampling intervals, 33, 68, and 131 d after application. Initial trends in NO_3 and Br amounts at the soil surface after 33 d showed reduced leaching with the LDC applicator. But later, with decreased leaching potential with decreased precipitation, samples taken in the middle of the growing season (68 d) and at the end (131 d) showed little downward movement of the injected anions regardless of injection method.

The first year of the yield study (1995) was drier than average with rainfall between application (May 17) and harvest (October 24) 3" below average for that period. Conditions in the spring of the second year (1996) were wet which delayed anion injection until July 1. From then to harvest (November 12), rainfall of 17" was 3" above average for that period.

Probably because leaching was limited by reduced rainfall, there were no corn yield differences between injection methods for any of the N rates in 1995. In 1996, when rainfall was more plentiful, for similar N rates, plots treated with the LCD applicator yielded an average of 7.6 bu/acre more corn than plots where the conventional knife applicator was used. Based on yield/N-rate regression analysis, it was estimated that in 1996 leaching loss via conventional knife application was nearly 23% more than with LCD injection. Results for the end-of-season corn stalk nitrate test were consistent with yield results fitted with the regression equations (e.g., in 1996, the N rate of 140 lb/acre with the LCD should have and did test in the "low" range for the stalk test; and the 180 lb/acre rate should have and did test "optimal").

Leaching/Yield Field Study

The objectives of this two-phased study (IDALS, 1998) comparing application rate and placement methods under natural rainfall/field conditions were to 1) measure $\text{NO}_3\text{-N}$ concentrations and losses in subsurface drainage water and 2) evaluate corn yield response to N applied with three applicators/systems. In addition to the LCD and conventional knife applicators (used with a chisel plow tillage system), the point-injector fertilizer applicator (PIFA) was used in conjunction with a ridge-tillage system. As shown in Figure 2, the PIFA injects fertilizer about 3-4" deep in rows of points with about 8" point-to-point spacing and with minimal soil or residue disturbance. When utilized with ridge tillage (injections made on the shoulder), the concept used to reduce leaching of applied N is that the ridge can act as an "umbrella" with a greater percentage of water infiltrating in the valleys than through the ridges. This should be particularly true during the intense rains when rain drop splash and runoff from the ridge to the valley is the greatest. The reduced water movement through the ridge and the point-injected N should lessen $\text{NO}_3\text{-N}$ leaching.

To determine leaching, the quantity and quality (with respect to $\text{NO}_3\text{-N}$ concentrations) of subsurface water draining from the soil through plastic drain tubes placed in the center of 50'

wide plots (125' long) were monitored. Drain tubes between plots prevented "cross-over" of drainage from one plot to another, and resulted in a drain spacing of 25', but these border tubes were not monitored. Corn yield response to 40, 80, and 120 lb N/acre in a corn-soybean rotation was measured using the LCD and PIFA applicators; for the knife applicator, response for these rates plus the 160 lb N/acre rate was measured. For continuous corn, corresponding rates were 80, 120, and 160 lb N/acre for the LCD and PIFA and were 120, 160, and 200 lb N/acre for the knife. In addition, the late spring soil nitrate test (LSNT) was used for both rotations, and a 145 lb N/acre rate of manure was used for continuous corn. The soils in the plots were mostly Webster and Nicollet clay loams, and the plot-drainage system was such that for the corn-soybean rotation, one-half the plot (10 rows) on one side of the center drain tube was planted to corn one year and soybeans the next (and vice-versa for the 10 rows on the other side); therefore, the drainage water from the plot represented the quality of water for the rotation rather than individual crops.

Corn yields, averaged for 1995-97, for corn in the corn-soybean rotation and continuous corn are given in Figures 3 and 4, respectively. As shown, corn yields for the rotation were generally higher than for continuous corn, particularly at the higher N rates and presumably from a soybean N credit and other soil quality factors. In addition, the response to N fertilization was greater and less variable for the corn-soybean rotation than for continuous corn.

The highest corn yields recorded resulted from the use of the LCD applicator at the 120 lb N/acre for corn following soybean; PIFA yields for corn following soybean were very similar at this rate. The continuous corn rotation had the highest yields at the 160 lb N/acre rate using the LCD applicator, but yields were less than for the corn-soybean rotation. Overall, the LCD yields surpassed those of the knife at all N rates. Use of the LSNT, which involves a split application of either 40 or 80 lb N/acre preplant followed by a side-dress application when the corn is about 12" tall, did reduce N use somewhat with an average total of 142 lb N/acre applied to corn in rotation with soybeans and 152 lb N/acre applied to continuous corn. Use of the PIFA with ridge-tillage, with one exception, generally gave yields below use of the LCD and knife applicators at comparative rates. Poorer weed control, both chemical and mechanical (in part because herbicides were banded, not broadcasted) was blamed for the lower yields with ridge tillage. Continuous corn yields for plots that received manure at a nominal rate of 145 available N were just slightly lower than the fertilizer knife applications at 160 and 200 lb N/acre.

Figures 3 and 4 also show that $\text{NO}_3\text{-N}$ concentrations for the LCD and PIFA treatments were generally below the 10 ppm drinking water standard (the dotted line), with knife applications of 160 and 200 lb N/acre on continuous corn having the highest concentrations. The LCD applicator, while having the highest yields, generally had lower $\text{NO}_3\text{-N}$ concentrations in subsurface drainage. The manure treatment on continuous corn also had concentrations below 10 ppm. This study will be continued at least two more years to determine if these trends continue over a longer term.

Summary

Results of the studies presented here indicate that localized compaction and doming over a band of N fertilizer may reduce $\text{NO}_3\text{-N}$ leaching and improve N-use efficiency in a Midwestern

rainfed corn field, particularly during years that have greater than average rainfall after N fertilization. The same concept of diverting infiltrating/percolating water away from the zone of N application might be applied to the use of the point injector fertilizer applicator as was done with ridge tillage. Additional work is needed to refine this concept and the methodology/equipment to achieve the desired results. Two applications possibly deserving of study are the use of this concept to protect fall-applied N against leaching, and use of such an applicator simultaneous with cultivation.

Literature Cited

- Baker, J.L., K.L. Campbell, H.P. Johnson, and J.J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. *J. Environ. Qual.* 4:406-412.
- Baker, J.L., T.S. Colvin, S.J. Marley, and M. Dawelbeit. 1989. A point-injector applicator to improve fertilizer management. *Appl. Engr. Agric.* 5:334-338.
- Baker, J.L., and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. *J. Environ. Qual.* 10:519-522.
- Baker, J.L., J.M. Laflen, and M.M. Schreiber. 1997. Potential for localized compaction to reduce leaching of injected ions. *J. Environ. Qual.* 26:387-393.
- Gast, R.G., W.W. Nelson, and G.W. Randall. 1978. Nitrate accumulation in soils and loss in tile drainage following nitrogen applications to continuous corn. *J. Environ. Qual.* 7:258-261.
- Hatfield, J.L., D.B. Jaynes, J.L. Baker, M.R. Burkart, R.S. Buchmiller, and P.J. Soenksen. 1995. Walnut Creek watershed: Linking farming practices to environmental quality, *In: Proceedings, Clean Water - Clean Environment - 21st Century, March 5-8, 1995, Kansas City, MO* (p. 125-128; vol. III).
- IDALS. 1998. Agricultural drainage well research and demonstration project. Annual Report, Iowa Dept. of Agric. and Land Stewardship, Des Moines, IA, 23p.
- Johnson, H.P., and J.L. Baker. 1982. Field-to-stream transport of agricultural chemicals and sediment in an Iowa watershed: Part I. Database for model testing (1976-1978). Report No. EPA-600/S3-82-032, Environmental Research Laboratory, Athens, GA.
- Johnson, H.P., and J.L. Baker. 1984. Field-to-stream transport of agricultural chemicals and sediment in an Iowa watershed: Part II. Database for model testing (1979-1980). Report No. EPA-600/S3-84-055, Environmental Research Laboratory, Athens, GA.
- Juo, A.S.R., and R. Lal. 1979. Nutrient profile in a tropical Alfisol under conventional and no-till systems. *Soil Sci.* 127:168-173.
- Kanwar, R.S., J.L. Baker, and D.G. Baker. 1988. Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. *Trans. ASAE* 31:453-461.

- Kanwar, R.S., J.L. Baker, and J.M. Laflen. 1985. Nitrate movement through the soil profile in relation to tillage system and fertilizer application method. *Trans. ASAE* 28:1802-1807.
- Kiuchi, M., R. Horton, and T.C. Kaspar. 1994. Leaching characteristics of replaced soil columns as influenced by subsurface flow barriers. *Soil Sci. Soc. Am. J.* 58:1212-1218.
- Kladivko, E.J., G.E. Van Scoyoc, E.J. Monke, K.M. Oates, and W. Pask. 1991. Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. *J. Environ. Qual.* 20:264-270.
- Rabalais, N.N., W.J. Wiseman, Jr., R.E. Turner, B.K.S. Gupta, and Q. Dortch. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* 19:368-407.
- Ressler, D.E., R. Horton, J.L. Baker, and T.C. Kaspar. 1997. Testing a nitrogen applicator designed to reduce leaching losses. *Applied Eng. in Agric.* 13:345-350.
- Ressler, D.E., R. Horton, J.L. Baker, and T.C. Kaspar. 1998a. Evaluation of localized compaction and doming to reduce anion leaching losses using lysimeters. *J. Environ. Qual.* 27:910-916.
- Ressler, D.E., R. Horton, T.C. Kaspar, and J.L. Baker. 1998b. Localized soil mangement in fertilizer injection zone to reduce nitrate leaching. *Agron. J.* 90 (in press).
- Tyler, D.D., and G.W. Thomas. 1977. Lysimeter measurements of nitrate and chloride losses from soil under conventional and no-tillage corn. *J. Environ. Qual.* 6:63-66.
- USDA-NASS. 1998. Agricultural Chemical Usage - 1997 Field Crop Summary, Report Ag Ch 1 (98), ERS-NASS, Herndon, VA, 106 p.

Table 1. Average anion concentrations and leaching losses from soil columns.

Tillage	Placement	Drainage [†] (in)	Conc. [‡]		Loss [§]	
			NO ₃ -N	Br	NO ₃ -N	Br
			----- (mg/L) -----		----- (%) -----	
NT	B	3.9	13.8	26.5	17.7	29.9
	PI	4.0	13.6	41.6	15.6	42.8
	CPI	3.9	16.7	2.9	22.6	3.1
CP	B	4.0	17.7	44.4	22.0	46.4
	PI	3.9	21.6	42.7	22.4	43.1
	CPI	4.1	22.6	6.6	31.3	6.7

[†] Simulated rainfall averaged 5.0".

[‡] Flow-weighted average concentration.

[§] An average of 73 lb NO₃-N/acre was present in the 18 columns at the time of simulation; an average of 85 lb Br/acre was applied to the 18 columns.

Table 2. Percentage leaching of anion tracers with lysimeter drainage.

Application method	First Period (July-Nov.)*		Second Period (Nov.-Nov.)*	
	Rainfall intensity		Rainfall intensity	
	low	high	low	high
knife	5.7	5.0	17.2	21.5
broadcast	2.8	3.6	14.1	15.8
LCD	1.8	1.1	12.1	9.9

* About 4" of drainage occurred in each period.

Figure 1. Schematic of point-injector fertilizer applicator (PIFA).

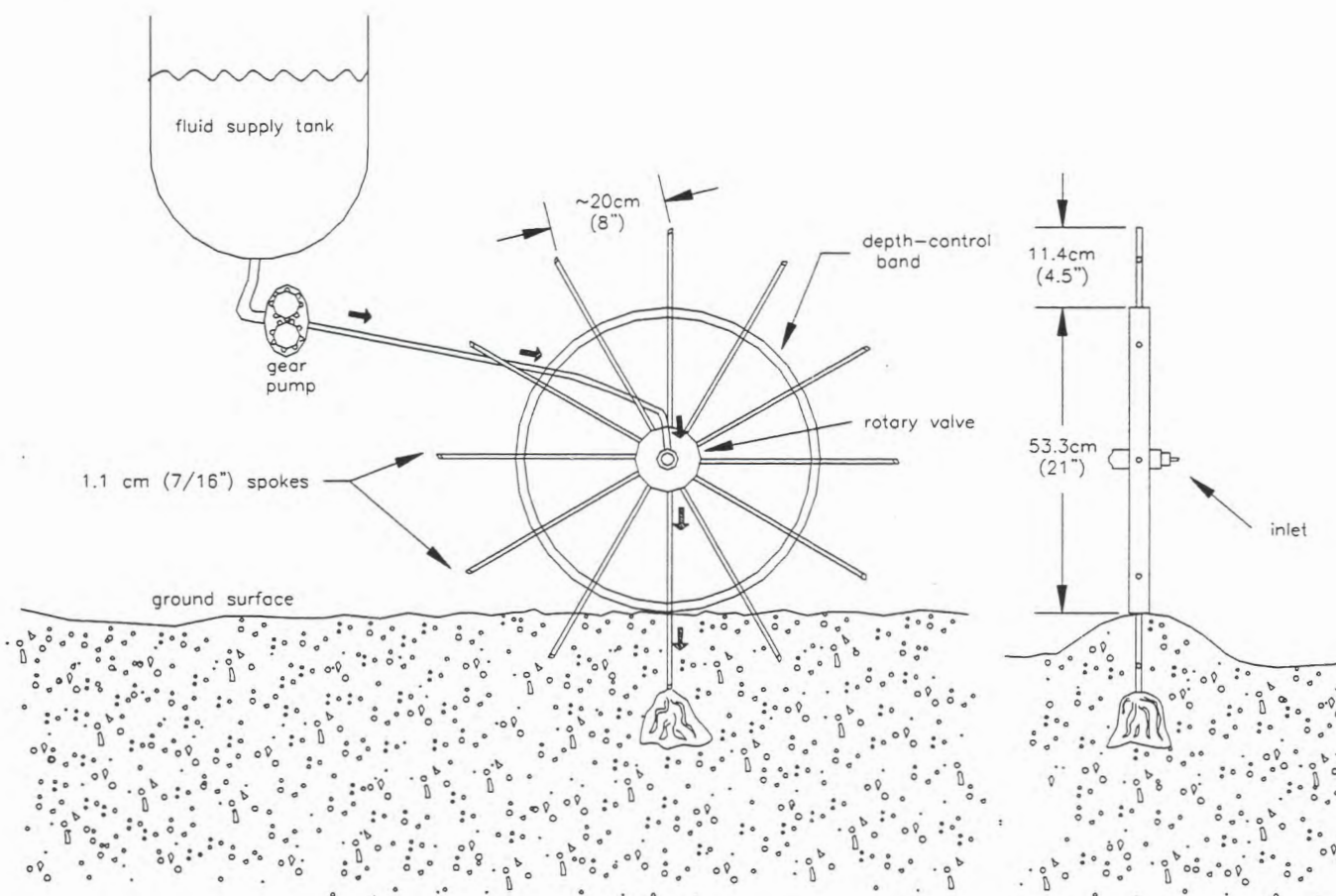


Figure 2. Schematic of localized compaction and doming (LCD) applicator.

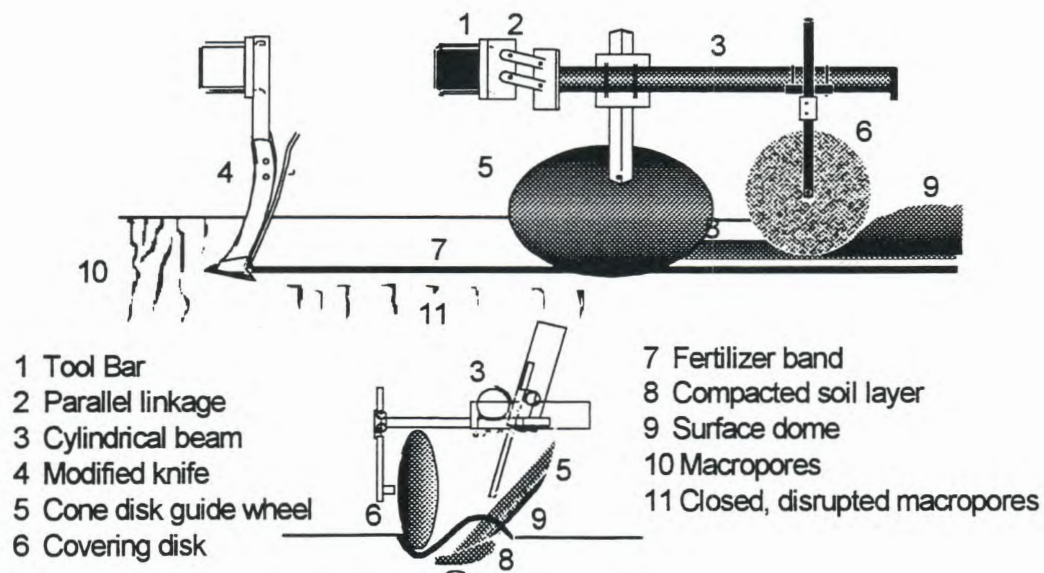


Figure 3. Corn yield and seasonal flow weighted nitrate-nitrogen concentration for corn/soybean rotation, 1995-97.

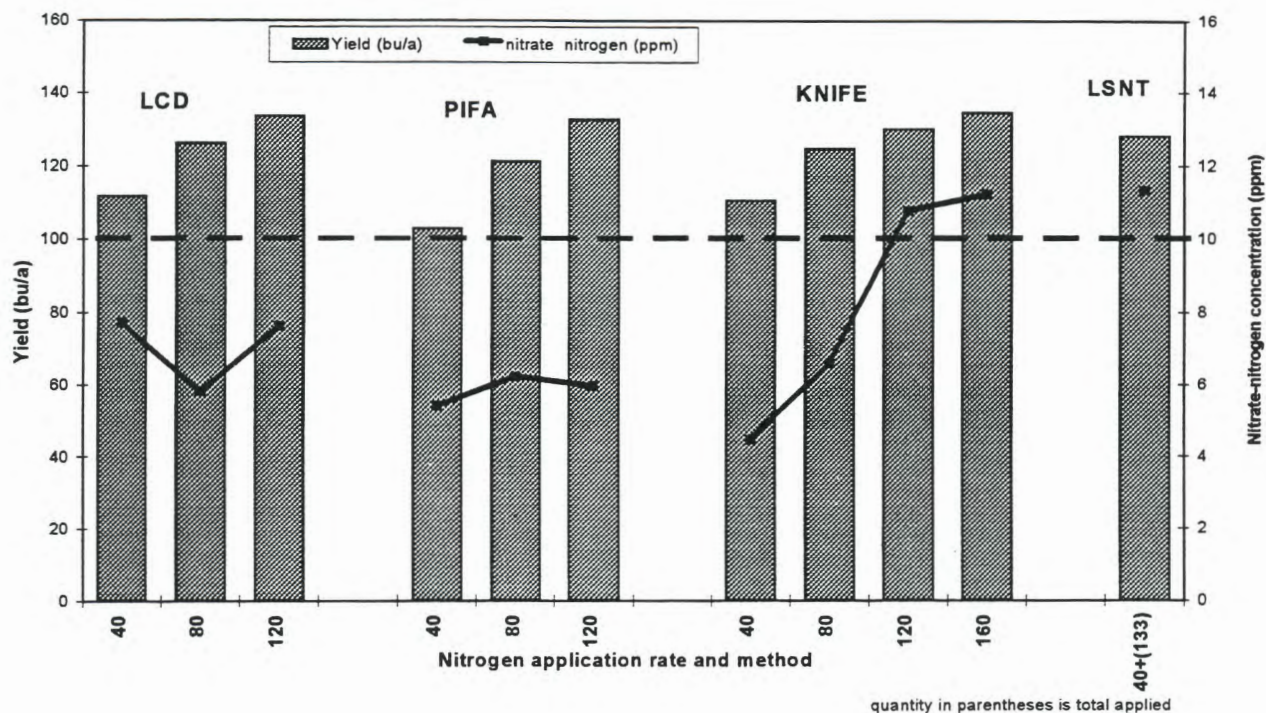


Figure 4. Corn yield and seasonal flow weighted nitrate-nitrogen concentration for continuous corn, 1995-97.

